

University of Groningen

Exploring the relations among physical fitness, executive functioning, and low academic achievement

de Bruijn, A. G. M.; Hartman, E.; Kostons, D.; Visscher, C.; Bosker, R. J.

Published in:
Journal of Experimental Child Psychology

DOI:
[10.1016/j.jecp.2017.10.010](https://doi.org/10.1016/j.jecp.2017.10.010)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Final author's version (accepted by publisher, after peer review)

Publication date:
2018

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

de Bruijn, A. G. M., Hartman, E., Kostons, D., Visscher, C., & Bosker, R. J. (2018). Exploring the relations among physical fitness, executive functioning, and low academic achievement. *Journal of Experimental Child Psychology*, 167, 204-221. <https://doi.org/10.1016/j.jecp.2017.10.010>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Exploring the relations between physical fitness, executive functioning and low academic achievement

Introduction

There is accumulating evidence for relations between the physical and the cognitive domain. Children with higher levels of physical fitness perform better cognitively, as shown by their academic abilities in mathematics, reading, and language (Fedewa & Ahn, 2011; Santana et al., 2016). Physical fitness can be defined as a set of characteristics used to perform physical activities (Ortega, Ruiz, Castillo, & Sjöström, 2008). It entails the full range of physical capacities and can be subdivided into various components, for instance aerobic fitness, muscular strength, and skill-related fitness. The relation between physical fitness and academic achievement seems to be especially strong in the domain of mathematics (Chaddock-Heyman et al., 2015; Chomitz et al., 2008; Lambourne et al., 2013), although relations have also been found for reading (e.g. Chomitz et al., 2008) and spelling (Pindus et al., 2016).

Interestingly, physical fitness has not only been related to academic achievement, but also to other cognitive functions, such as executive functioning (see Chaddock, Pontifex, Hillman, & Kramer, 2011). Executive functions are a subset of higher-order cognitive functions that are involved in organizing and controlling goal-directed behavior (Diamond, 2013). Three core executive functions are generally distinguished: inhibition, shifting, and working memory (Miyake et al., 2000). Inhibition is defined as the ability to withhold dominant, automatic behaviors that are irrelevant for the task at hand. Shifting, or task-switching, refers to the ability to shift attention forwards and backwards between multiple tasks in order to easily adapt to changing situations. Verbal and visuospatial working memory are required for the monitoring and coding of incoming information in order to revise and replace information that is no longer relevant by new, more useful information. Well-developed executive functions are a prerequisite for good academic performance. Reading,

spelling, and mathematics are complex skills that rely heavily on the ability to inhibit automatic behavior, to shift between strategies, and to update working memory (Best, Miller, & Naglieri, 2011).

Several explanations have been proposed to account for the relationship between physical activity and executive functioning. Generally, these mechanisms can be categorized into two broad categories: physiological mechanisms and learning/developmental mechanisms. According to physiological mechanisms, aerobic activity at a moderate-to-vigorous intensity level leads to an upregulation of several growth factors (e.g. brain-derived neurotrophic factor) and monoamines (dopamine, epinephrine and norepinephrine), resulting in short- and long-term changes in the structure and functioning of brain regions that are responsible for learning (Best, 2010). Learning/developmental mechanisms explain the relation between physical activity and cognition by referring to the learning experiences that take place while being physically active, which have beneficial effects on cognitive development as well. In this sense, it is not the physical exertion per se that is important, but rather the cognitive engagement during physical activity and the cognitive demands inherent in motor skill learning and coordination of complex movements (Sibley & Etnier, 2003). It has been suggested that both mechanisms are complementary, meaning that a combination of moderate-to-vigorous physical activity and cognitive-demanding activities will have the strongest effects on executive functioning (Kempermann et al., 2010).

As executive functions are essential cognitive skills for good academic performance and because physical fitness seems to be related to both executive functioning and academic achievement, it can be hypothesized that the relation between physical fitness and academic achievement goes via executive functioning (Howie & Pate, 2012). A study by Van der Niet, Hartman, Smith and Visscher (2014) provided the first support for the mediating effect of executive functioning by reporting that the direct relation between physical fitness and academic achievement disappeared once executive functioning was taken into account. It thus

seems that beneficial effects of physical fitness on academic achievement are brought about via improved executive functions.

This assumption is highly relevant when considering the population of low academic achievers, which we define as the lowest 25% performing students in one or more academic domains (Siegel, 1999). This < 25% criterion is widely used as criterion for having low achievement and/or learning difficulties (e.g. Cirino, Fuchs, Elias, Powell, & Schumacher, 2015; Geary, 2013; Geary & Hoard, 2005; Swanson & Jerman, 2006; see also Murphy et al., 2007 for a review on cutoff criteria for mathematical difficulties). There is evidence for the validity of this cutoff score for example from studies showing that students with learning difficulties can be separated from their normally achieving peers on different types of tasks based on this cutoff (see Siegel 1999). Only a few studies have focused on this specific population, however, which is unfortunate, as low achievement in school can have devastating consequences for a child's development. Poor academic performance greatly increases the likelihood of being referred to special education (Van der Veen, Smeets & Derriks, 2010). This referral can hamper cognitive development of low achieving students even more, as they seem to make more progress in regular than in special education (Baker, Wang, & Walberg, 1994; Lipsky & Gartner, 1996; Peetsma, Vergeer, Roeleveld, & Karsten, 2001). In addition, low academic achievement in primary school is a strong predictor of dropping out of school altogether (Rumberger & Lim, 2008).

In line with the hypothesis that executive functioning mediates the relation between physical fitness and academic achievement, results indicate that lower academic performance is related to lower levels of executive functioning (Van der Sluis, de Jong, & van der Leij, 2004; Van der Sluis, van der Leij, & de Jong, 2005). The pattern of cognitive deficit seems to depend on the domain of low performance, with learning-lagged students in the domain of language showing different deficits than those in the domain of mathematics (Tang, 2007). The relation between executive functioning and academic performance seems to be especially

strong in the domain of mathematics (Bull & Lee, 2014; Cragg & Gilmore, 2014), where the most pronounced relations have been found with working memory (De Smedt et al., 2009; Passolunghi, Mammarella, & Altoè, 2008). The few studies that specifically examined children with spelling disorders only focused on working memory and found that spelling problems were related to worse performance on verbal working memory, but not on visuospatial working memory (Brandenburg et al., 2014; Wimmer & Mayringer, 2002; Wimmer & Schurz, 2010).

The problems associated with low academic achievement underline the need for early intervention. As the poorer academic performance of low achievers seems to be related to less well-developed executive functions and lower levels of physical fitness, improvements in physical fitness, by being related to executive functioning, could be beneficial for academic performance. There are indeed indications that physical activity interventions are particularly successful for students with cognitive and/or physical problems, probably because they have the most room for improvement (Diamond, 2012; Diamond & Lee, 2011; Drollette et al., 2014; Sibley & Beilock, 2007). Empirical evidence for the mediating effect of executive functioning is still scarce, however, and it remains unknown whether there are specific direct and indirect relations between physical fitness, executive functioning, and academic achievement. Considering the need for interventions, particularly for students with low academic achievement, research is necessary to determine whether executive functions mostly fulfil a mediating role between physical fitness and academic achievement, or that executive functions and physical fitness each have strong direct relations with academic achievement.

Therefore, the present study aims to examine the relation between physical fitness and low academic achievement in mathematics and spelling. As there are strong relations between physical fitness and executive functioning, and between executive functioning and academic achievement, it will be examined whether physical fitness and executive functioning are independently related to academic achievement in mathematics and spelling or whether

executive functioning is a mediator in the relation between physical fitness and low academic achievement in these domains. Following Miyake and Friedman's theory of executive functioning (2000) which states that there are three core executive functions, the following executive functions will be taken into account: inhibition (Stroop test), working memory (verbal- Digit span task, visuospatial- Visual span task) and shifting (Modified Wisconsin Task Sorting Test). Previous studies have shown that there are specific relations between physical fitness and academic achievement (e.g. Chaddock-Heyman et al., 2015), and executive functioning and academic achievement (e.g. Tang, 2007). It is therefore expected that there are specific mediating relations between physical fitness and components of executive functioning, depending on the academic domain involved. In order to examine these specific relations, the four executive functions mentioned above will be taken into account as separate variables.

Method

Participants

A total of 510 children of twelve primary schools in the Northern part of the Netherlands took part in this study. Children were in second or third grade (Mean age = 8.05, $SD = .72$). Not all participants were included for analyses due to missing data ($N = 33$), resulting in a total sample of 477 children. Five participants had missing values on mathematics achievement and four other participants on spelling achievement. These participants were left out of analysis in that specific domain, leaving 472 participants for mathematics and 473 participants for spelling. The study was approved by the Ethics Committee of the Center for Human Movement Sciences of the University Medical Center Groningen, University of Groningen. Informed consent was provided for all children by their legal guardian.

Children were classified into five achievement levels (A-scores, B-scores, C-scores, D-scores or E-scores) for the domain of mathematics and the domain of spelling based on

their norm-referenced scores on a standardized national achievement test. Children with A-scores represent the 25% highest performing children on the standardized achievement test. B-scores represent the 25% of students who perform far to just above the national average. Students with C-scores are the 25% of students who score just- below to far-below the average national score. D-scores represent the 15% of students who perform far-below the national average. Students with E-scores are the 10% lowest performing children. We grouped students with D-scores and E-scores together into one group making up the lowest 25% performing students and classified them as low academic achievers. The other three groups (75%) were grouped together as well and were classified as average-to-high achieving students. Children of the lowest achievement level (> 25%) were consequently compared to children of the other three achievement levels by creating a dichotomous variable (low achievers vs. average-to-high achievers). Descriptive statistics of the low achieving and higher achieving groups are shown in Table 1.

Table 1.

Descriptive statistics of low- achieving and average-to-high achieving children in mathematics and spelling.

	Mathematics		Spelling	
	Low (<i>n</i> = 73)	Average-to- high (<i>n</i> = 399)	Low (<i>n</i> = 52)	Average-to-high (<i>n</i> = 421)
Age (yr)	8.1 (0.7)	8.0 (0.7)	8.3 (0.8)	8.0 (0.7)
Grade				
Second	41 (56%)	200 (50%)	18 (35%)	221 (52%)
Third	32 (44%)	199 (50%)	34 (65%)	200 (48%)
Sex				
Boys	26 (36%)	182 (46%)	32 (61%)	178 (42%)
Girls	47 (64%)	217 (54%)	20 (39%)	243 (58%)

Note. Values are mean \pm standard deviation for age only, and *n* (%) for grade and sex.

Materials

Physical fitness tests. Four subtests of the standardized Eurofit test battery (van Mechelen, van Lier, Hlobil, Crolla, & Kemper, 1991) were used to measure four aspects of physical fitness: aerobic fitness (20m shuttle run, in number of completed tracks), muscular strength (standing broad jump, in centimeters), running speed and agility (10x5m shuttle run, in seconds) and upper-limb agility (plate-tapping, in seconds). The Eurofit is a reliable ($r = .62$ to $.97$) and valid measure of children's fitness (Adam, Klissouras, Ravazzolo, Renson, & Tuxworth, 1988), and has been well-established in previous studies (Fransen et al., 2014).

The 20m endurance shuttle run test was used as a measure of aerobic fitness. In this test children ran back and forth between two lines that are 20m apart within a specific time interval that was indicated by audio signals. The interval between each successive signal became smaller as the test proceeded. The test ended when a child failed to reach a line prior to the signal on two successive trials. The number of completed tracks was recorded as final score.

Muscular strength was measured with the standing broad jump test (SBJ). In this test children stood behind a line with their feet slightly apart. They used a two foot take-off to jump as far as possible, swinging the arms to create forward drive and landing on both feet again without falling backwards. Children got two attempts of which the longest distance jumped (in cm) was recorded as a test result.

As a measure of skill-related physical fitness, measures of both upper-limb and lower-limb were recorded. The 10x5m shuttle run test was administered to measure speed and agility of lower limb movement. In this test, children ran back and forth between two lines that were 5m apart. The time needed to run this distance ten times (50m in total) was recorded.

The plate tapping test measures speed of upper-limb movement. In this test, children had to alternately touch two discs that were 80cm apart as fast as possible. The time needed to complete 25 full cycles was recorded. The best of two attempts was used as a test result.

Executive functioning.

Inhibition. The Stroop task was used as a measure of inhibition (Golden, 1978). Children were presented with three cards resembling three conditions. In the first condition children were asked to read aloud a series of color words printed in black ink (Word task). In the second condition children had to name the color of rectangles (printed in red, yellow, green or blue ink: Color task). The last condition presented children with the names of colors printed in conflicting colors (in red, yellow, green or blue) of which children had to name the color of the ink (Color-word task). In each condition children had 45 seconds to name as many words or colors as possible. The number of correctly named words or colors was used as a score for the respective condition, with a maximum score of 100 for each condition. A Stroop inference score was calculated by subtracting the score of the Color task from the score of the Color-Word task. The Stroop inference score has proven to be a reliable measure for measuring inhibition in children (test-retest reliability is .81; Neyens & Aldenkamp, 1997).

Verbal working memory. The Digit span backward task was used to measure verbal working memory (Wechsler, 1987). In the Digit span backward the instructor read aloud a sequence of digits and asked the child to recall this sequence in a reverse order. Spans increased from two to eight digits, with three sequences in a span, making up a maximum score of 21. The test was stopped when a child failed to correctly recall at least two of the three sequences within one span. The digit span backward is a reliable (test re-test reliability is .82) and valid measure of children's verbal working memory (Wechsler, 1987).

Visuospatial working memory. The Visual span backward task was used as a measure of visuospatial working memory (Wechsler, 1987). In this task, children had to repeat a

sequence of squares tapped on a card containing eight printed squares in reverse order. The number of tapped sequences increased from two to seven. The child had to repeat two different sequences within each span, resulting in a maximum score of twelve. The test ended when a child failed to recall two sequences of the same length. The Visual span backward is a reliable (test re-test reliability is .75) and valid measure of visuospatial working memory in children (Wechsler, 1987).

Shifting. A modified version of the Wisconsin Card Sorting test (MWCST) was used to measure shifting. The MWCST is an adapted version of the regular Wisconsin Card Sorting test and is considered more appropriate for children (Cianchetti, Corona, Foscoliano, Contu, & Sannio-Fancello, 2007). In this test, the child received 48 cards, each of which has a unique color (red, yellow, blue or green), unique shape (circle, cross, triangle or star) and unique number of shapes (one, two, three or four). The child had to sort these cards according to one of the characteristics by using feedback on whether a card was sorted correctly or incorrectly. The sorting rule changed after six consecutive correct responses. The task ended when all 48 cards were sorted or when six different sorting rules were used within six consecutive trials. Two scores were used to measure categorizing ability: number of perseverative errors (i.e. a failure to change the sorting rule after negative feedback) and categorizing efficiency, which was calculated by granting six points to every correctly applied sorting rule and one point to each card that was not used (ranging from 0 to 48). Both are valid measures of shifting ability in children (Cianchetti et al., 2007).

Academic achievement. As a measure of academic achievement, ability scores in mathematics and spelling were derived from the Dutch child academic monitoring system (CAMS; Gillijns & Verhoeven, 1992). Most Dutch primary schools use this system, to keep track of students' progress in academic skills throughout primary education. Twice a year each child is tested on mathematics, reading, and spelling. Raw scores on these tests are converted to a proficiency score and level with a norm table which is based on scores of a large,

representative sample of Dutch primary school students. By using these norm scores, a student's performance in one year can be easily compared to scores reached in previous years to see how much progress a child is making (Janssen, & Hickendorff, 2008; Janssen, Verhelst, Engelen, & Scheltens, 2010; De Wijs, Kamphuis, Kleintjes, & Tomesen, 2010).

The *mathematics* test is a valid and reliable ($r = .93$ to $.96$) test which is taken individually (Janssen et al., 2010). It measures performance in geometry, number sense and computation, and algebra. The *spelling* test is a valid and reliable ($r = .90$ to $.93$) measure of spelling performance and comprises two subtests (De Wijs et al., 2010). The first test is a dictation in which a teacher reads a sentence out loud and repeats a specific word from this sentence. Children were asked to correctly write down this repeated word. In the second test children were presented with lists of words and from each list they have to recognize the word that was spelled incorrectly.

Procedure

Children were individually tested on the executive functioning tasks by instructed researchers in a quiet room at their own school. Approximately two weeks later, children's muscular strength and aerobic and skill-related fitness were tested during two regular physical education classes. In one lesson the standing broad jump, 10x5m run and plate-tapping test were administered. The 20m shuttle run test was administered in another lesson. Each instructor was familiarized with the executive functioning and physical fitness tests during a training session of two hours. The mathematics and spelling tests were administered by the school at a fixed time point.

Data source

This study is based on secondary data-analysis of an existing dataset, coming from an intervention study on the effects of physically active academic lessons on primary school students' physical fitness and cognitive performance. Only data of the pretest of this study was used for the present study, hence ruling out any intervention effects. Several articles were

published based on this research project. These studies mainly looked at the effects of an intervention involving physically active academic lessons on physical fitness (de Greeff et al., 2016a; de Greeff et al., 2016b), executive functioning (de Greeff et al., 2016b), academic engagement (Mullender-Wijnsma et al., 2015b), or academic achievement (Mullender-Wijnsma et al., 2015a; Mullender-Wijnsma et al., 2015b, Mullender-Wijnsma et al., 2016; Mullender-Wijnsma, 2017). Furthermore, two other studies have been published using only the pretest data, namely: a study on the relation between physical fitness and academic achievement in children with and without a social disadvantage (de Greeff et al., 2014); and a study on the mediating role of physical fitness in the relationship between socioeconomic status and executive functions (de Greeff, 2016). In none of these studies the relations between physical fitness, executive functioning and academic achievement were examined simultaneously, which is why we wrote the present manuscript.

All executive functioning measures that were used in the original research project were included in the present study as well. Not all measures for academic achievement and physical fitness were used in the present study however. We decided not to use scores on technical reading, as those rely less on executive functioning, but instead are more dependent on phonological decoding and word identification (Sesma, Mahone, Levine, Eason, & Cutting, 2009). Although in the original study scores on arithmetic speed were obtained, it was expected that those would rely less on executive functioning, but rather on arithmetic fact retrieval (van der Sluis, de Jong, & van der Leij, 2007). As such, we decided to only use the general mathematics score.

For physical fitness, we decided not to include the measures of handgrip strength (maximum isometric strength of the hand and forearm muscles) and sit-ups (endurance of the abdominal and hip-flexor muscles), which are both measures of muscular strength. We included one measure per aspect of physical fitness and decided to use the standing broad jump (SBJ) as measure of muscular strength, because it has been found to be strongly related

to other measures of upper and lower body strength (Castro-Piñero et al., 2010). The SBJ can therefore be considered a more general index of muscular strength. The measures for abdominal strength (sit-ups) and handgrip strength were expected to be more specific measures reflecting the muscular strength of a specific part of the body.

Data Analysis

Initial data analyses were conducted in IBM SPSS Statistics 23.0 for Windows. First, data were screened for missing values and outliers. Missing data was observed on one or more variables for 101 of the cases. Little's MCAR test was not significant ($\chi^2(82) = 88.01, p = .31$) suggesting that the data was missing completely at random. Participants were excluded when they had missing values on both of the outcome variables (mathematics and spelling; $N = 33$). For the other 68 cases, full-information maximum likelihood estimation was performed in Mplus 7.31 (Muthén & Muthén, 1998-2006) to estimate missing data by computing a likelihood function for each individual based on available data. FIML is a highly recommended approach to handle missing data (see for example Enders, 2010).

A confirmatory factor analysis (CFA) was conducted in Mplus to see whether the suggested factor structure was a good fit to the data. Two multi-indicator factors were created, one for shifting (with the indicators MWCST efficiency and MWCST preservative errors) and one for physical fitness (with the indicators standing broad jump, 20m shuttle run, 10x5m shuttle run and plate-tapping). In addition, three single-indicator factors were created for inhibition (indicated by the Stroop inference score), verbal working memory (indicated by the digit span backward) and visuospatial working memory (indicated by the visual span backward), with their corresponding factor loadings fixed at 1 and indicator error variance (e) fixed at the product of the measure's sample variance ($\text{VAR}(X)$) and $1 - \rho$, where ρ refers to the reliability of the measure (.81 for Stroop inference, .82 for digit span backward, and .75 for visual span backward (see above); Brown, 2006, p. 139). Covariances between verbal working memory, visuospatial working memory and shifting were added because significant

correlations between those variables were found in a correlation analysis (see Appendix 1).

The factor structure resulted in a good model fit.

This factor structure was consequently used to fit two multilevel structural equation (SEM) models in Mplus using weighted least squares means and variances adjusted (WLSMV) estimation. The conventional Chi-square statistic (χ^2) and related p-value, the root mean square error of approximation (RMSEA), and comparative fit index (CFI) were used as fit indices, with cut-offs of $> .05$ (p-value), .06 and .90 respectively (Hu & Bentler, 1999). Two models were built in which both academic domains were included as outcome variables: one model with direct relations between physical fitness and executive functioning as predictors of academic achievement level in mathematics and spelling, and a second model in which indirect paths (via executive functioning) were added between physical fitness and academic achievement level in mathematics and spelling.

The outcome variables for academic achievement level were dichotomous variables comparing the lowest performers in mathematics or spelling to their higher achieving peers. Gender and age were entered into all models as covariates and were related to physical fitness, executive functioning and academic achievement because of expected relations between those concepts. Standardized estimates of the path coefficients and corresponding significance values were obtained for significance testing. Direct and indirect effects were obtained using maximum-likelihood, corresponding standard errors were calculated using the multivariate Delta method (Muthén, 2011).

Results

Overall mean scores on the cognitive and physical tests and mean scores for the average-to-high achieving and low achieving students in mathematics and spelling separately are presented in Table 2.

Confirmatory factor analysis

Before examining the direct and indirect relations of the structural model, a confirmatory factor analysis was conducted to see whether the factor structure in the measurement model was a good representation of the data. The model with two multi-indicator factors (shifting and physical fitness), three single-indicator factors (verbal working memory, visuospatial working memory and shifting) and covariances between verbal working memory, visuospatial working memory and shifting proved to be a good fit to the data ($\chi^2 (20) = 45.29, p = .001$, RMSEA = .05, CFI = .95). Although the χ^2 - statistic was below the traditional fit cutoff ($p > .05$), we decided to accept the model as both other fit indices were above their cutoff and as we preferred minimal post-hoc modifications. In addition, the χ^2 is sensitive for sample size, model size and distribution of variables and is therefore not considered very useful by most researchers (Hu & Bentler, 1998).

Main analyses

The factor structure tested above was consequently used to test two structural models. In the first model only direct relations between physical fitness and academic achievement level and between executive functioning and academic achievement level were added to examine whether physical fitness and executive functioning were predictive of academic achievement level in mathematics. The model was not a good fit to the data ($\chi^2 (48) = 128.05, p < .001$, RMSEA = .06, CFI = .81) and results were not further interpreted.

Table 2.

Means and standard errors on the physical fitness and executive functioning measures for average-to-high achieving and low achieving students in mathematics and spelling.

	Mathematics			Spelling	
	Total	Average-to-high	Low	Average-to-high	Low
	(n = 477)	(n = 399)	(n = 73)	(n = 421)	(n = 52)
Fitness					
SBJ (cm)	124.4 (1.0)	125.0 (1.1)	120.4 (2.6)	124.2 (1.0)	126.8 (3.3)
Plate tapping (sec) ^a	27.9 (.2)	17.8 (.2)	18.6 (.4)	17.9 (.2)	18.1 (.5)
10x5m SR (sec) ^a	24.5 (.1)	24.3 (.1)	25.7 (.3)	24.5 (.1)	24.6 (.4)
20m SR (n tracks)	31.3 (.7)	31.9 (.8)	27.3 (1.6)	31.5 (.8)	29.9 (2.0)
Cognition					
Inhibition	17.8 (.4)	18.0 (.4)	16.7 (.9)	17.7 (.4)	18.3 (1.0)
VWM (n correct)	5.1 (.1)	5.2 (.1)	4.2 (.2)	5.2 (.1)	4.5 (.2)
VSWM (n correct)	5.7 (.1)	5.9 (.1)	4.2 (.2)	5.7 (.1)	5.4 (.3)
Shifting					
Efficiency	21.4 (.5)	22.2 (.6)	16.6 (1.1)	21.7 (.6)	19.5 (1.4)
Pers. errors (n) ^a	4.5 (.2)	4.1 (.2)	5.7 (.5)	4.2 (.2)	5.3 (.7)
<i>Note:</i> SR = shuttle run, SBJ = standing broad jump VWM = verbal working memory, VSWM = visuospatial working memory.					

The second model with added indirect relations between physical fitness and academic achievement via executive functioning proved to fit the data well ($\chi^2 (39) = 66.19, p = .004$, RMSEA = .04, CFI = .94). Again the χ^2 - statistic was below the traditional fit cutoff ($p > .05$), but as discussed above we decided to accept the model based on the other fit indices. Significant direct relations in the model are presented in Figure 1 (the full model including non-significant paths, factor loadings, error terms and covariances can be found in Appendix 2).

The covariates age ($\beta = .34, p < .001$, 95% CI: .21 to .47) and gender ($\beta = .26, p < .001$, 95% CI: .16 to .36) were significantly related to physical fitness, indicating better performance of older students compared to their younger peers and boys compared to girls.

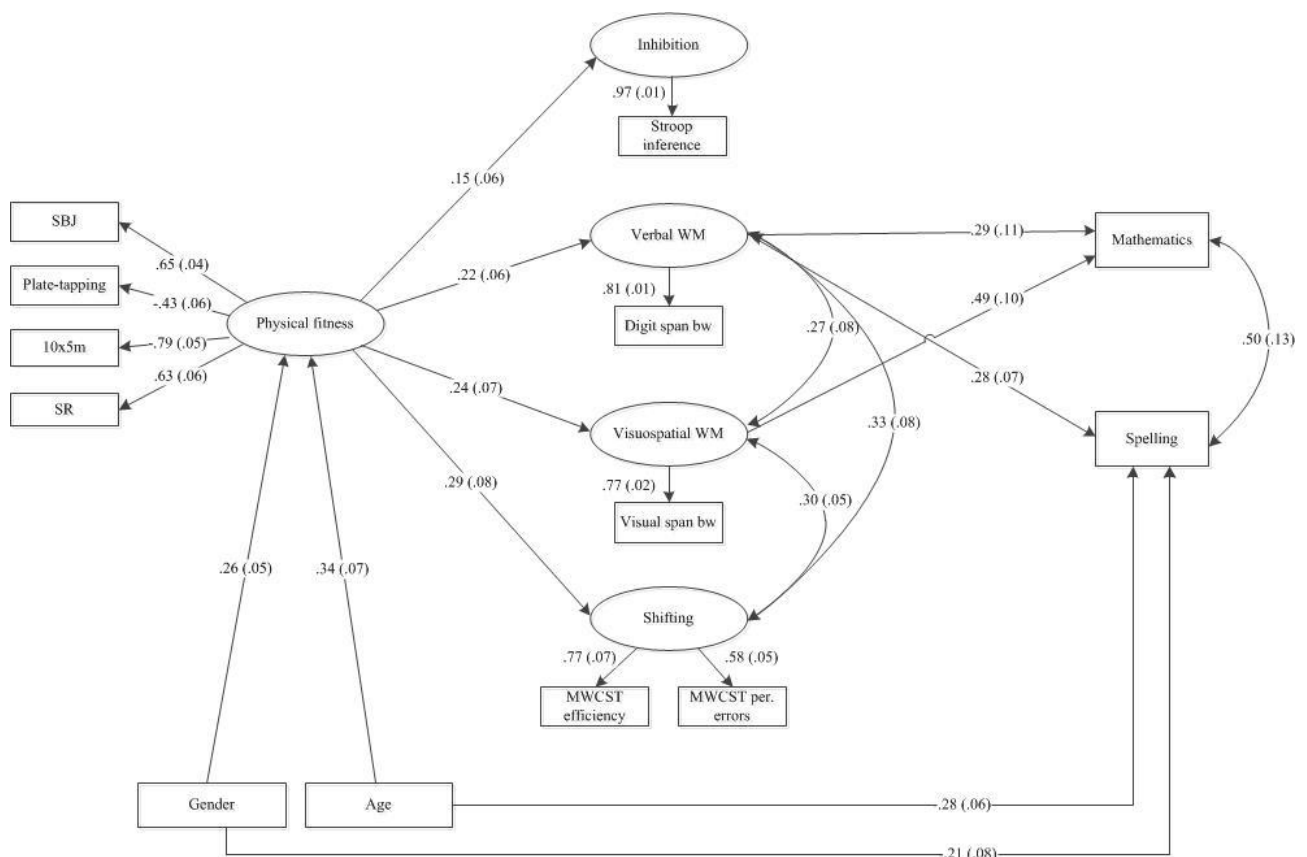


Figure 1.

Significant paths between physical fitness, executive functioning and achievement level (low vs. high) in mathematics and spelling, controlling for gender and age. Standardized path coefficients (β) and associated standard errors are displayed in the figure.

Mathematics

In total a significant 51.2% of the variance of the difference between low achievers and average to high achievers in mathematics was explained by the direct and indirect paths with physical fitness and executive functioning, controlling for age and gender ($p < .001$). The total effect from physical fitness to mathematics achievement level was significant ($\beta = .31, p < .001, 95\% \text{ CI: } .14 \text{ to } .49$). The indirect relations between physical fitness and mathematics achievement level via executive functioning accounted for a significant 69.1% of the total effect ($\beta = .22, p < .001, 95\% \text{ CI: } .15 \text{ to } .29$). The direct effect from physical fitness to mathematics achievement level accounted for 30.9% of the total effect, which was not significant ($\beta = .10, p = .33, 95\% \text{ CI: } -.10 \text{ to } .29$).

Direct relations. Verbal working memory ($\beta = .29, p = .007, 95\% \text{ CI: } .08 \text{ to } .50$) and visuospatial working memory ($\beta = .49, p < .001, 95\% \text{ CI: } .29 \text{ to } .70$) significantly predicted categorization in the lowest compared to the higher achievement levels. Children with lower verbal working memory, and visuospatial working memory were more likely to be in the lowest compared to the higher achievement levels. Physical fitness ($\beta = .10, p = .33, 95\% \text{ CI: } -.10 \text{ to } .29$), inhibition ($\beta = .05, p = .55, 95\% \text{ CI: } -.22 \text{ to } .13$) and shifting ($\beta = .10, p = .41, 95\% \text{ CI: } -.19 \text{ to } .40$) were not significant predictors of being in the lowest compared to the higher achievement levels.

Indirect relations. The indirect path between physical fitness and mathematics achievement level via verbal working memory ($\beta = .06, p = .03, 95\% \text{ CI: } .01 \text{ to } .12$) and visuospatial working memory ($\beta = .12, p < .001, 95\% \text{ CI: } .05 \text{ to } .19$) were significant. Lower physical fitness was related to lower verbal and visuospatial working memory, which both significantly differentiated between the lowest and the higher achieving students. There were no significant indirect relations between physical fitness and mathematics achievement level via inhibition ($\beta = .01, p = .55, 95\% \text{ CI: } -.02 \text{ to } .03$) and shifting ($\beta = .03, p = .41, 95\% \text{ CI: } -.04 \text{ to } .10$).

Spelling

In total 22.9% of the variance of the difference between low achievers and average-to-high achievers in spelling was explained by the direct and indirect relations with physical fitness and executive functioning, controlling for age and gender ($p < .001$). The total effect from physical fitness to spelling achievement level was not significant ($\beta = .16, p = .23, 95\% \text{ CI: } -.10 \text{ to } .41$). The indirect relations between physical fitness and spelling achievement via executive functioning accounted for a significant 65.4% of the total effect ($\beta = .10, p = .02, 95\% \text{ CI: } .02 \text{ to } .19$). The direct effect from physical fitness to spelling achievement level accounted for 34.6% of the total effect, which was not significant ($\beta = .06, p = .69, 95\% \text{ CI: } -.21 \text{ to } .32$).

Direct relations. Verbal working memory ($\beta = .29, p < .001, 95\% \text{ CI: } .16 \text{ to } .41$) significantly predicted categorization in the lowest compared to the higher achievement levels. Children with lower scores on verbal working memory were more likely to be in the lowest compared to the higher achievement levels. Physical fitness ($\beta = .06, p = .69, 95\% \text{ CI: } -.21 \text{ to } .32$), inhibition ($\beta = -.04, p = .55, 95\% \text{ CI: } -.22 \text{ to } .13$), visuospatial working memory ($\beta = .07, p = .71, 95\% \text{ CI: } -.29 \text{ to } .43$) and shifting ($\beta = .11, p = .48, 95\% \text{ CI: } -.19 \text{ to } .40$) did not significantly predict low spelling achievement level when compared to the higher achievement levels.

Both the covariates age ($\beta = -.28, p < .001, 95\% \text{ CI: } -.40 \text{ to } -.16$) and gender ($\beta = -.21, p = .01, 95\% \text{ CI: } -.37 \text{ to } -.05$) were significantly related to spelling achievement, with girls and younger students performing better compared to boys and older students.

Indirect relations. The indirect path between physical fitness and spelling achievement level via verbal working memory was significant ($\beta = 0.06, p = .01, 95\% \text{ CI: } .01 \text{ to } .11$), indicating that poorer physical fitness was related to poorer verbal working memory, which in turn predicted low spelling achievement. There were no significant indirect paths between physical fitness and spelling achievement via inhibition ($\beta = -.01, p = .61, 95\% \text{ CI: } -$

.03 to .02), visuospatial working memory ($\beta = .02$, $p = .71$, 95% CI: -.07 to .10) and shifting ($\beta = .03$, $p = .48$, 95% CI: -.05 to .12).

Discussion

In agreement with previous studies, a positive relation between physical fitness and academic achievement was found in both domains (Fedewa & Ahn, 2011; Santana et al., 2016). Importantly, this relation was not direct, but indirect, via executive functioning. A model with only direct relations between physical fitness and executive functioning on the one hand and low academic achievement on the other hand was not a good fit to the data, showing that physical fitness was not an independent predictor of academic achievement. Rather, in the relation between physical fitness and academic achievement, executive functioning seems to act as a restrictor. Although longitudinal studies are needed to confirm our findings, these results suggest that when physical fitness is used to improve academic achievement, it should first exert positive effects on executive functioning in order to be successful.

The mediating role of executive functioning in the relation between physical fitness and academic achievement has been found in a previous study as well (Van der Niet et al., 2014). Our study extends these results by showing that the mediating role of executive functioning is not general but specific. Verbal working memory was a mediator between physical fitness and low achievement in both domains, whereas visuospatial working memory had a mediating role only in mathematics. An explanation for these specific mediating relations may lay in the different developmental trajectories of the four executive functions, which are caused by the difference in developmental rate of brain areas supporting these executive functions (Olson & Luciana, 2008; Best & Miller, 2010). Inhibition and working memory are thought to develop first, laying the foundations for the development of shifting ability, which is the latest maturing executive function (Best & Miller, 2010; Olson & Luciana, 2008; Purpura, Schmitt, & Ganley, 2017). Although inhibition and working memory

start to develop at the same time, the development of working memory is more prolonged, showing growth into late adolescence. Inhibitory performance stabilizes by the early school years and improvements in inhibitory skill do not strongly relate to neural changes after this age (Best & Miller, 2010). Inhibition might therefore not be that sensitive for the influences of physical fitness in the age group that we examined. The development of working memory on the other hand seems to be particularly striking in the age group examined in our study (Best & Miller, 2010), probably making this aspect of executive functioning the most sensitive for influences of physical fitness. As we have shown in this study, verbal working memory in its turn is important for both mathematics and spelling performance, and visuospatial working memory specifically aids mathematics performance.

Alternatively, or additionally, the fact that we found mediating relations only via working memory is in line with previous studies reporting the strongest predicting value of working memory for academic achievement (e.g. Bull & Lee, 2014; van der Ven, Kroesbergen, Boom, & Leseman, 2012). These relations have led to the suggestion that working memory is a common source for both inhibition and shifting, which plays a dominant role and undermines the influences of inhibition and shifting (Bull & Lee, 2014). According to this assumption, only relations between working memory and academic achievement will be significant when inhibition, shifting and working memory are examined simultaneously, which is in accordance with the results of our study. Interestingly, when we analysed academic achievement as a continuous outcome measure (see Appendix 3 for the results), shifting was found to be a significant mediator between physical fitness and academic achievement in both mathematics and spelling. This suggests that shifting is important for academic achievement, but that it is not specifically predictive of low academic achievement.

One important and related issue is the task impurity problem that is associated with executive functioning. Different measures (e.g. for inhibition the Flanker task, Stroop task or Stop-Signal task) and different scores (e.g. Stroop difference score or Stroop inference score)

have been used to measure executive functioning in different studies. Further, it has been argued that many of the tasks used to measure inhibition also require involvement of working memory, and tasks used to measure shifting also tap into inhibitory ability and working memory capacity (see Best & Miller, 2010). According to some researchers all tasks require the involvement of working memory to some degree, as it is needed to keep task requirements in mind (Garron, Bryson, & Smith, 2008; Van der Ven et al., 2012). This argument could also explain why working memory is often found to be the dominant executive function in the relation with academic achievement. The task impurity problem is an important issue to take into account in future research. It seems useful to include several tasks or scores for each executive function to get a more reliable measure of the true latent ability level of executive functioning. Still, even though in our study we only used one measure for each executive function, we believe that the executive functioning measures used were able to distinguish between students with low and students with higher levels of executive functioning, as we found significant relations between physical fitness and each of the executive functions.

Our results suggest that physical fitness interventions have the potential to improve academic achievement of low achieving students. The mediating effect of executive functioning further suggests that these improvements in academic achievement will be preceded by enhanced executive functions, either verbal working memory (in spelling) or both verbal and visuospatial working memory (in mathematics), although longitudinal or intervention studies are needed to confirm this suggestion. In a world where children are getting increasingly unfit (e.g. Schokker, Visscher, Nooyens, Van Baak, & Seidell, 2007), these results are very encouraging as they suggest that physical fitness interventions designed to improve children's physical health can be beneficial for cognition and academic achievement as well.

Modeling Relations in Mathematics versus Spelling

The predicting value of physical fitness and executive functioning was much lower in the domain of spelling than in the domain of mathematics, with 22.9% of explained variance in spelling versus 51.2% of explained variance in mathematics. This result coincides with the conclusion mentioned earlier, which stated that the relation between executive functioning and academic performance is especially strong in the domain of mathematics (Bull & Lee, 2014; Cragg & Gilmore, 2014). Also, this finding is in line with results of a meta-analysis reporting that the largest effects of physical activity on children's cognitive outcomes could be found for mathematics achievement (Fedewa & Ahn, 2011). Not only do there seem to be specific relations between physical fitness, executive functioning, and academic achievement level depending on the academic domain involved, but the strength of these relations also seems to differ per domain. Results of our study suggest that improvements in physical fitness will be especially beneficial for achievement in mathematics.

Strengths, Limitations and Future Directions

Strengths of this study include the large sample size and the examination of specific rather than general relations between physical fitness, executive functioning and academic achievement.

A first limitation of this study is that we were not able to make statements on the causality of our findings as we took a cross-sectional approach. It would be interesting to see whether physical fitness also has causal effects on academic achievement via specific executive functions by means of an experimental designed physical fitness program with clear stimulation of executive functioning in mind.

Secondly, low achievers in mathematics and low achievers in spelling were examined separately in this study. Low achievement often extends beyond one domain however, making children with low achievement in mathematics more likely to be low achievers in spelling as well (Tang, 2007). It would be interesting to see whether the relations that we found for low achievement in mathematics and spelling would also apply in case of simultaneous low

achievement in both mathematics and spelling. These students seem to experience an additive combination of the problems that students with a single learning deficit face (van der Sluis et al., 2004), suggesting that a model with a combination of the significant pathways for mathematics and spelling would apply. Unfortunately we were not able to study this hypothesis due to the low number of students achieving simultaneously low in both mathematics and spelling, but this would be an interesting issue to address in future studies.

Lastly, the sample included in our study was unequally distributed regarding their age, with girls on average being younger than boys. This unequal age distribution can probably also account for the unexpected negative relation that was found between age and spelling achievement, indicating that younger students performed better on the spelling test. Girls generally perform better in spelling (Allred, 1990) and as girls in our study were significantly younger than boys, this could have led to the negative relation between age and spelling. Still, we think our results apply to the general population of primary school students in this age group as the effects of age and gender were controlled for by including them in the model as covariates.

Conclusion

Although the mediating effect of executive functioning in the relation between physical fitness and academic achievement has been found before, our study is the first to show that the relation between physical fitness and academic achievement is mediated by specific executive functions, depending on the domain involved. Verbal working memory mediated the relation between physical fitness and low achievement in both domains, whereas visuospatial working memory specifically mediated between physical fitness and low mathematics achievement. Different paths predicted low achievement in mathematics compared to low achievement in spelling, with higher predicting values for mathematics than for spelling. These results suggest that physical fitness interventions could be very successful in improving low academic achievement, especially in mathematics, when they improve

executive functions, as these seem to be strongly linked to academic achievement.

Intervention studies are needed to show whether improvements in physical fitness can indeed be used to improve academic achievement of low academic achievers. Importantly, these type of physical fitness interventions will have the additional benefit that they exert positive effects on children's health, physical fitness, and motor development.

References

- Adam, C., Klissouras, V., Ravazzolo, M., Renson, R., & Tuxworth, W. (1988). *Eurofit: European Test of Physical Fitness*. Rome: Council of Europe, Committee for the Development of Sport.
- Allred, R. A. (1990). Gender differences in spelling achievement in grades 1 through 6. *The Journal of Educational Research*, 83(4), 187-193. doi: 10.1080/00220671.1990.10885955
- Baker, E. T., Wang, M. C., & Walberg, H. J. (1994). The effects of inclusion on learning. *Educational Leadership*, 52(4), 33-35.
- Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review*, 30(4), 331-351. doi: 10.1016/j.dr.2010.08.001
- Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development*, 81(6), 1641-1660. doi:10.1111/j.1467-8624.2010.01499.x
- Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences*, 21(4), 327-336. doi: 10.1016/j.lindif.2011.01.007
- Brandenburg, J., Kleszczewski, J., Fischbach, A., Schuchardt, K., Büttner, G., & Hasselhorn, M. (2014). Working memory in children with learning disabilities in reading versus spelling: Searching for overlapping and specific cognitive factors. *Journal of Learning*

Disabilities, 48(6), doi: 0022219414521665

Brown T. A. (2006). *Confirmatory factor analysis for applied research*. New York, NY: Guilford Press; 2006.

Bull, R., & Lee, K. (2014). Executive functioning and mathematics achievement. *Child Development Perspectives*, 8(1), 36-41. doi: 10.1111/cdep.12059

Castro-Piñero, J., Ortega, F. B., Artero, E. G., Girela-Rejón, M. J., Mora, J., Sjöström, M., & Ruiz, J. R. (2010). Assessing muscular strength in youth: usefulness of standing long jump as a general index of muscular fitness. *The Journal of Strength & Conditioning Research*, 24(7), 1810-1817. doi: 10.1519/JSC.0b013e3181ddb03d

Chaddock, L., Pontifex, M. B., Hillman, C. H., & Kramer, A. F. (2011). A review of the relation of aerobic fitness and physical activity to brain structure and function in children. *Journal of the International Neuropsychological Society*, 17(6), 975-985. doi: 10.1017/S1355617711000567

Chaddock-Heyman, L., Erickson, K. I., Kienzler, C., King, M., Pontifex, M. B., Raine, L. B., Hillman, C. H., & Kramer, A. F. (2015). The role of aerobic fitness in cortical thickness and mathematics achievement in preadolescent children. *PloS one*, 10(8), e0134115. doi: 10.1371/journal.pone.0138166

Chomitz, V. R., Slining, M. M., McGowan, R. J., Mitchell, S. E., Dawson, G. F., & Hacker, K. A. (2008). Is there a relationship between physical fitness and academic achievement? Positive results from public school children in the northeastern United States. *Journal of School Health*, 79(1), 30-37. doi: 10.1111/j.1746-1561.2008.00371.x

Cianchetti, C., Corona, S., Foscoliano, M., Contu, D., & Sannio-Fancello, G. (2007). Modified Wisconsin Card Sorting Test (MCST, MWCST): normative data in children 4-13 years old, according to classical and new types of scoring. *The Clinical Neuropsychologist*, 21(3), 456-478. doi: 10.1080/13854040600629766

Cragg, L., & Gilmore, C. (2014). Skills underlying mathematics: The role of executive

- function in the development of mathematics proficiency. *Trends in Neuroscience and Education*, 3(2), 63-68. doi: 10.1016/j.tine.2013.12.001
- de Greeff, J. W. (2016). *Physically active academic lessons: Effects on physical fitness and executive functions in primary school children* (Doctoral dissertation).
Rijksuniversiteit Groningen, Groningen.
- De Greeff, J. W., Hartman, E., Mullender-Wijnsma, M. J., Bosker, R. J., Doolaard, S., & Visscher, C. (2014). Physical fitness and academic performance in primary school children with and without a social disadvantage. *Health Education Research*, 29(5), 853-860. doi: 10.1093/her/cyu043
- de Greeff, J. W., Hartman, E., Mullender - Wijnsma, M. J., Bosker, R. J., Doolaard, S., & Visscher, C. (2016a). Effect of physically active academic lessons on body mass index and physical fitness in primary school children. *Journal of School Health*, 86(5), 346-352. doi: 10.1111/josh.12384
- de Greeff, J. W., Hartman, E., Mullender-Wijnsma, M. J., Bosker, R. J., Doolaard, S., & Visscher, C. (2016b). Long-term effects of physically active academic lessons on physical fitness and executive functions in primary school children. *Health Education Research*, 31(2), 185-194. doi: 10.1093/her/cyv102
- De Smedt, B., Janssen, R., Bouwens, K., Verschaffel, L., Boets, B., & Ghesquière, P. (2009). Working memory and individual differences in mathematics achievement: A longitudinal study from first grade to second grade. *Journal of Experimental Child Psychology*, 103, 186–201. doi:10.1016/j.jecp.2009.01.004
- De Wijs, A., Kamphuis, F., Kleintjes, F., & Tomesen, M. (2010). *Spelling voor groep 3 tot en met 6: wetenschappelijke verantwoording* (Scientific justification for spelling examination in first-fourth grade). Arnhem: Cito.
- Diamond, A. (2012). Activities and programs that improve children's executive functions. *Current Directions in Psychological Science*, 21(5), 335-341. doi:

10.1177/0963721412453722

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, 64, 135–168. doi:

10.1146/annurev-psych-113011-143750

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science*, 333(6045), 959-964. doi: 10.1126/science.1204529

Drollette, E. S., Scudder, M. R., Raine, L. B., Moore, R. D., Saliba, B. J., Pontifex, M. B., & Hillman, C. H. (2014). Acute exercise facilitates brain function and cognition in children who need it most: an ERP study of individual differences in inhibitory control capacity. *Developmental Cognitive Neuroscience*, 7, 53-64. doi:

10.1016/j.dcn.2013.11.001

Enders, C. K. (2010). *Applied missing data analysis*. Guilford Press.

Fedewa, A. L., & Ahn, S. (2011). The effects of physical activity and physical fitness on children's achievement and cognitive outcomes: a meta-analysis. *Research Quarterly for Exercise and Sport*, 82(3), 521-535. doi: 10.1080/02701367.2011.10599785

Fransen, J., Deprez, D., Pion, J., Tallir, I. B., D'Hondt, E., Vaeyens, R., Lenoir, M., & Philippaerts, R. M. (2014). Changes in physical fitness and sports participation among children with different levels of motor competence: a 2-year longitudinal study. *Pediatric Exercise Science*, 26(1), 11-21. doi: 10.1123/pes.2013-0005

Geary, D. C. (2013). Early foundations for mathematics learning and their relations to learning disabilities. *Current Directions in Psychological Science*, 22(1), 23-27. doi: 10.1177/0963721412469398

Geary D. C., & Hoard M. (2005). Learning disabilities in arithmetic and mathematics: theoretical and empirical perspectives. In Campbell, J. I. D. (Ed), *Handbook of Mathematical Cognition* (pp. 253-267). New York, NY: Psychology Press.

Gillijns, P. & Verhoeven, L. (1992). Het Cito-leerlingvolgsysteem: Met het oog op de praktijk. *Pedagogische Studiën*, 69, 291-296.

- Golden, C. J. (1978). *The Stroop color and word test: A manual for clinical and experimental uses*. Chicago, IL: Stoelting.
- Howie, E. K., & Pate, R. R. (2012). Physical activity and academic achievement in children: A historical perspective. *Journal of Sport and Health Science*, 1(3), 160-169. doi: 10.1016/j.jshs.2012.09.003
- Hu, L., & Bentler, P. M. (1998). Fit indices in covariance structure modeling: Sensitivity to underparameterized model misspecification. *Psychological Methods*, 3(4), 424. doi: 10.1037/1082-989X.3.4.424.
- Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indices in covariance structure analysis: conventional criteria versus new alternatives. *Structural Equation Modeling*, 6, 1–55. doi: 10.1080/10705519909540118
- Janssen, J., & Hickendorff, M. (2008). *Categories analysis for the mathematics CAMS test*. Arnhem: Cito.
- Janssen, J., Verhelst, N., Engelen, R., & Scheltens, F. (2010). *Wetenschappelijke Verantwoording Van de Toetsen Rekenen-Wiskunde Voor Groep 3 Tot en Met 8 (Scientific Justification for Mathematics Examination in First-Fifth Grade)*. Arnhem: Cito.
- Kempermann, G., Fabel, K., Ehninger, D., Babu, H., Leal-Galicia, P., Garthe, A., & Wolf, S. (2010). Why and how physical activity promotes experience-induced brain plasticity. *Frontiers in Neuroscience*, 4, 189. doi: 10.3389/fnins.2010.00189
- Kramer, A. F., Erickson, K. I., & Colcombe, S. J. (2006). Exercise, cognition, and the aging brain. *Journal of Applied Physiology*, 101(4), 1237-1242. doi: 10.1152/japplphysiol.00500.2006
- Lambourne, K., Hansen, D. M., Szabo, A. N., Lee, J., Herrmann, S. D., & Donnelly, J. E. (2013). Indirect and direct relations between aerobic fitness, physical activity, and academic achievement in elementary school students. *Mental Health and Physical*

- Activity*, 6(3), 165-171. doi: 10.1016/j.mhpa.2013.06.002
- Lipsky, D. K. & Gartner, A. (1996). Inclusion, school restructuring, and remaking of American society. *Harvard Educational Review*, 66, 762-796. doi: 10.17763/haer.66.4.3686k7x734246430
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe tasks”: A latent variable analysis. *Cognitive Psychology*, 41, 49–100. doi: 10.1006/cogp.1999.0734
- Mullender-Wijnsma, M. (2017). *Physically active learning: The effect of physically active math and language lessons on children’s academic achievement* (Doctoral dissertation). Rijksuniversiteit Groningen, Groningen.
- Mullender-Wijnsma, M. J., Hartman, E., de Greeff, J. W., Bosker, R. J., Doolaard, S., & Visscher, C. (2015a). Improving academic performance of school - age children by physical activity in the classroom: 1 - year program evaluation. *Journal of School Health*, 85(6), 365-371. doi: 10.1111/josh.12259
- Mullender-Wijnsma, M. J., Hartman, E., de Greeff, J. W., Bosker, R. J., Doolaard, S., & Visscher, C. (2015b). Moderate-to-vigorous physically active academic lessons and academic engagement in children with and without a social disadvantage: a within subject experimental design. *BMC Public Health*, 15(1), 404. doi: 10.1186/s12889-015-1745-y
- Mullender-Wijnsma, M. J., Hartman, E., De Greeff, J. W., Doolaard, S., Bosker, R. J., & Visscher, C. (2016). Physically active math and language lessons improve academic achievement: a cluster randomized controlled trial. *Pediatrics*, 137(3). doi: 10.1542/peds.2015-2743
- Murphy, M. M., Mazzocco, M. M., Hanich, L. B., & Early, M. C. (2007). Cognitive

- characteristics of children with mathematics learning disability (MLD) vary as a function of the cutoff criterion used to define MLD. *Journal of Learning Disabilities*, 40(5), 458-478.
- Muthén, B. (2011). Applications of causally defined direct and indirect effects in mediation analysis using SEM in Mplus. Retrieved April 1, 2017 from <http://www.statmodel.com/download/causalmediation.pdf>.
- Muthén, L. K., & Muthén, B. O. (1998–2006). *Mplus: Statistical Analysis with Latent Variables (4.2 edition.)*. Los Angeles: Muthén and Muthén.
- Neyens, L. G., & Aldenkamp, A. P. (1997). Stability of cognitive measures in children of average ability. *Child Neuropsychology*, 3(3), 161-170. doi: 10.1080/09297049708400639
- Olson, E. A., & Luciana, M. (2008). The development of prefrontal cortex functions in adolescence: Theoretical models and a possible dissociation of dorsal versus ventral subregions. In C. A. Nelson & M. Luciana (Eds.), *Handbook of Developmental Cognitive Neuroscience* (2nd ed., pp. 575–590). Cambridge, MA: MIT Press
- Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity*, 32(1), 1-11. doi: 10.1038/sj.ijo.0803774
- Passolunghi, M. C., Mammarella, I. C., & Altoè, G. (2008). Cognitive abilities as precursors of the early acquisition of mathematical skills during first through second grades. *Developmental Neuropsychology*, 33(3), 229-250. doi: 10.1080/87565640801982320
- Peetsma, T., Vergeer, M., Roeleveld, J., & Karsten, S. (2001). Inclusion in education: Comparing pupils' development in special and regular education. *Educational Review*, 53(2), 125-135.
- Pindus, D. M., Drollette, E. S., Scudder, M. R., Khan, N. A., Raine, L. B., Sherar, L. B., Esliger, D. W., Kramer, A. F., & Hillman, C. H. (2016). Moderate-to-vigorous physical

- activity, indices of cognitive control, and academic achievement in preadolescents.
The Journal of Pediatrics, 173, 136-142. doi: 10.1016/j.jpeds.2016.02.045
- Purpura, D. J., Schmitt, S. A., & Ganley, C. M. (2017). Foundations of mathematics and literacy: The role of executive functioning components. *Journal of Experimental Child Psychology*, 153, 15-34. doi: 10.1016/j.jecp.2016.08.010
- Rumberger, R. W., & Lim, S. A. (2008). *Why students drop out of school: A review of 25 years of research*. Santa Barbara, CA: University of California, California Dropout Research Project.
- Santana, C. C. A., Azevedo, L. B., Cattuzzo, M. T., Hill, J. O., Andrade, L. P., & Prado, W. L. (2016). Physical fitness and academic performance in youth: A systematic review. *Scandinavian Journal of Medicine & Science in Sports*, 27(6). doi: 10.1111/sms.12773
- Schokker, D. F., Visscher, T. L. S., Nooyens, A. C. J., Van Baak, M. A., & Seidell, J. C. (2007). Prevalence of overweight and obesity in the Netherlands. *Obesity Reviews*, 8(2), 101-107, doi: 10.1111/j.1467-789X.2006.00273.x
- Sesma, H. W., Mahone, E. M., Levine, T., Eason, S. H., & Cutting, L. E. (2009). The contribution of executive skills to reading comprehension. *Child Neuropsychology*, 15(3), 232-246. doi: 10.1080/09297040802220029
- Sibley, B. A., & Beilock, S. L. (2007). Exercise and working memory: An individual differences investigation. *Journal of Sport & Exercise Psychology*, 29(6), 783-791. doi: 10.1371/journal.pone.0044594
- Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: A meta-analysis. *Pediatric Exercise Science*, 15, 243–256. doi: 10.1123/pes.15.3.243
- Siegel, L. S. (1999). Issues in the definition and diagnosis of learning disabilities: A perspective on Guckenberger v. Boston University. *Journal of Learning Disabilities*, 32(4), 304-319. doi: 10.1177/002221949903200405

- Swanson, H. L., & Jerman, O. (2006). Math disabilities: A selective meta-analysis of the literature. *Review of Educational Research*, 76(2), 249-274. doi: 10.3102/00346543076002249
- Tang, W. (2007). *Cognitive processes related to reading and arithmetic* (Doctoral dissertation). University of British Columbia, Vancouver.
- Van der Niet, A. G., Hartman, E., Smith, J., & Visscher, C. (2014). Modeling relationships between physical fitness , executive functioning , and academic achievement in primary school children. *Psychology of Sport & Exercise*, 15(4), 319–325. doi: 10.1016/j.psychsport.2014.02.010
- Van der Sluis, S., de Jong, P. F., & van der Leij, A. (2004). Inhibition and shifting in children with learning deficits in arithmetic and reading. *Journal of Experimental Child Psychology*, 87(3), 239-266. doi: 10.1016/j.jecp.2003.12.002
- Van Der Sluis, S., de Jong, P. F., & van der Leij, A. (2007). Executive functioning in children, and its relations with reasoning, reading, and arithmetic. *Intelligence*, 35(5), 427-449. doi: 10.1016/j.intell.2006.09.001
- Van der Sluis, S., van der Leij, A., & de Jong, P. F. (2005). Working memory in Dutch children with reading-and arithmetic-related LD. *Journal of Learning Disabilities*, 38(3), 207-221.
- Van der Veen, I., Smeets, E., & Derriks, M. (2010). Children with special educational needs in the Netherlands: Number, characteristics and school career. *Educational Research*, 52(1), 15- 43. doi: 10.1080/00131881003588147
- Van der Ven, S. H. G., Kroesbergen, E. H., Boom, J., & Leseman, P. P. M. (2012). The development of executive functions and early mathematics. A dynamic relationship. *British Journal of Educational Psychology*, 82, 100-119. doi:10.1111/j.2044-8279.2011.02035.x
- Van Mechelen, W., Van Lier, W. H., Hlobil, H., Crolla, I., & Kemper, H. (1991).

Eurofit: Handleiding met Referentieschalen voor 12-tot en met 16-jarige Jongens en Meisjes in Nederland (Manual with Reference values for 12-16 Year Old Boys and Girls in the Netherlands). Haarlem: De Vrieseborch.

Wechsler, D. (1987). *WMS-R: Wechsler Memory Scale-Revised: Manual*. San Antonio, TX: Psychological Corporation.

Wimmer, H., & Mayringer, H. (2002). Dysfluent reading in the absence of spelling difficulties: A specific disability in regular orthographies. *Journal of Educational Psychology*, 94(2), 272.

Wimmer, H., & Schurz, M. (2010). Dyslexia in regular orthographies: manifestation and causation. *Dyslexia*, 16(4), 283-299. doi: 10.1002/dys.411

Appendix 1: Correlation matrices

Table 1.

Bivariate correlations between variables included in the models Mplus

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Mathematics	-												
2. Spelling	.23***	-											
3. Inhibition	.07	-.02	-										
4. VWM	.20***	.14**	.06	-									
5. VSWM	.36***	.05	.06	.19***	-								
Shifting													
6. MWCSTefficiency	.17***	.06	.01	.22***	.23***	-							
7. MWCST pers. errors	.12**	.08	-.08	.19***	.17***	.44***	-						
Fitness													
8. SBJ	.07	-.04	.08	.13**	.11*	.12*	.16***	-					
9. Plate-tapping	-.09	-.03	-.21***	-.12*	-.17***	-.13**	-.04	-.27***	-				
10. 10x5m SR	-.19***	-.01	-.09	-.07	-.18***	-.16***	-.18***	-.52***	.35***	-			
11. 20m SR	.11*	.03	.04	.08	.12*	.17***	.14**	.35***	-.17***	-.47***	-		
12. Gender	.08	-.12**	.03	-.01	.14**	-.03	.08	.20***	-.03	-.21***	.25***	-	
13. Age	-.01	-.14**	.06	.07	.15***	.14**	.14**	.28***	-.31***	-.20***	.02	.04	-

Note * < .05 ** < .01 *** < .001

VWM = Verbal working memory, VSWM = Visuospatial working memory, SBJ = Standing broad jump, SR = Shuttle run

Table 2. Correlations between latent and manifest variables included in the SEM-models

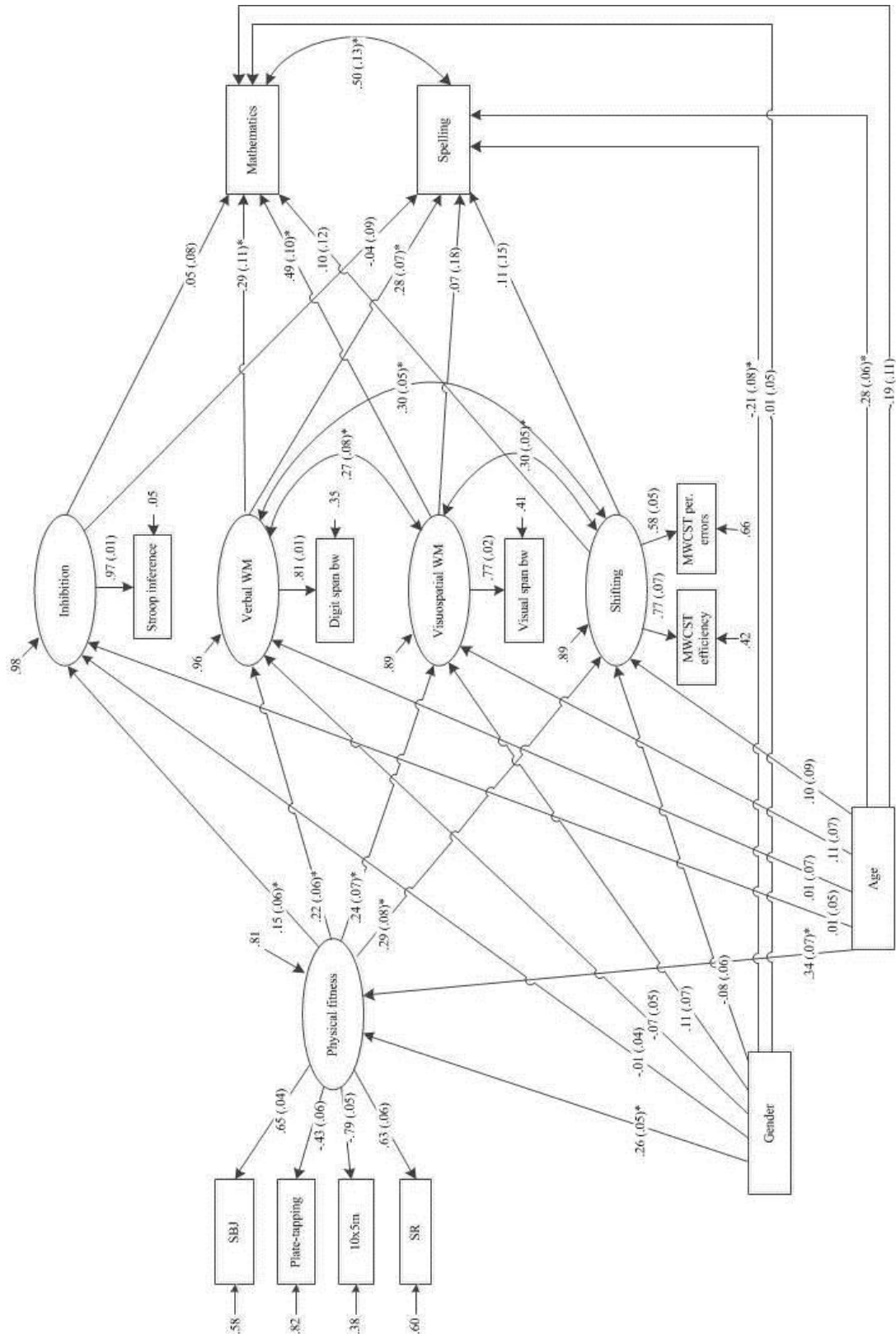
	1.	2.	3.	4.	5.	6.	7.
1. Fitness	-						
2. Inhibition	.13	-					
3. VWM	.15*	.08	-				
4. VSWM	.29***	.09	.30***	-			
5. Shifting	.33***	-.05	.37***	.39***	-		
6. Mathematics	.20*	.08	.23***	.48***	.21***	-	
7. Spelling	-.04	-.04	.12*	-.05	.06	.00	-

Note: * < .05 ** < .01 *** < .001

VWM = verbal working memory, VSWM = visuospatial working memory

Appendix 2: Full structural equation model presenting all included paths.

Note: * indicates significant paths between variables



Appendix 3: Analysis with continuous outcome variables

A model was fitted with continuous outcome variables for mathematics and spelling achievement. Based on modification indices, a covariance between age and plate-tapping was added to improve model fit. This resulted in a model which fitted the data well ($\chi^2(39) = 95.38, p < .001, RMSEA = .055, CFI = .95$). In total, 51.6% of the variance in mathematics achievement ($p < .001$) and 34.4% of the variance in spelling achievement ($p < .001$) was explained by this model including direct and indirect relations between physical fitness, executive functioning and academic achievement.

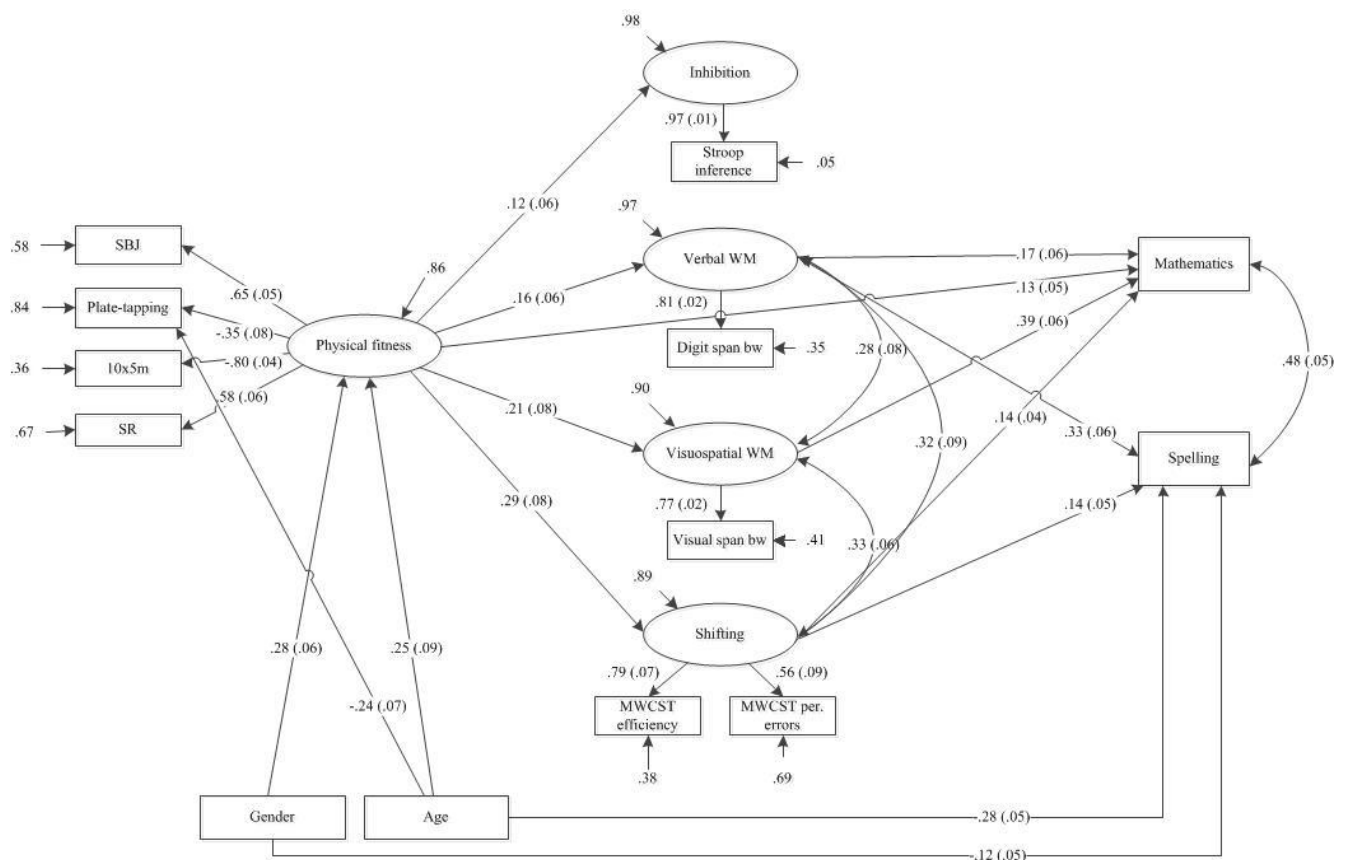
Mathematics

Verbal working memory ($\beta = .17, p = .008, 95\% \text{ CI: } .04 \text{ to } .29$), visuospatial working memory ($\beta = .39, p < .001, 95\% \text{ CI: } .27 \text{ to } .51$) and shifting ($\beta = .14, p = .001, 95\% \text{ CI: } .06 \text{ to } .23$) were significant predictors of mathematics achievement. The total effect of physical fitness to mathematics achievement was significant ($\beta = .28, p < .001, 95\% \text{ CI: } .20 \text{ to } .36$). Physical fitness was both directly ($\beta = .13, p = .017, 95\% \text{ CI: } .02 \text{ to } .23$) and indirectly ($\beta = .15, p < .001, 95\% \text{ CI: } .08 \text{ to } .22$) related to mathematics achievement. The total indirect effect from physical fitness to mathematics achievement accounted for a significant 54.9% of the total effect. The direct effect accounted for a significant 45.1% of the total effect. The indirect paths between physical fitness and mathematics achievement via visuospatial working memory ($\beta = .08, p = .011, 95\% \text{ CI: } .02 \text{ to } .15$) and via shifting ($\beta = .04, p = .003, 95\% \text{ CI: } .01 \text{ to } .07$) were found to be significant. The indirect path via verbal working memory just failed to reach significance ($\beta = .03, p = .061, 95\% \text{ CI: } -.001 \text{ to } .06$).

Spelling

Verbal working memory ($\beta = .33, p < .001, 95\% \text{ CI: } .22 \text{ to } .44$) and shifting ($\beta = .14, p = .003, 95\% \text{ CI: } .05 \text{ to } .24$) were significant predictors of spelling achievement. The total effect of physical fitness to spelling achievement was significant ($\beta = .26, p < .001, 95\% \text{ CI: } .07 \text{ to } .35$). Physical fitness was only indirectly ($\beta = .11, p = .001, 95\% \text{ CI: } .04 \text{ to } .17$) related

to spelling achievement. The total indirect effect from physical fitness to spelling achievement accounted for a significant 50.9% of the total effect. The direct effect accounted for 49.1% of the total effect, which was not significant ($\beta = .10$, $p = .12$, 95% CI: $-.03$ to $.24$). The indirect paths between physical fitness and spelling achievement via verbal working memory ($\beta = .05$, $p = .015$, 95% CI: $.01$ to $.10$) and via shifting ($\beta = .04$, $p = .012$, 95% CI: $.01$ to $.07$) were found to be significant.



Conclusions

In line with the results of our model with dichotomous outcome variables for mathematics and spelling achievement, we found significant direct and indirect relations with/via verbal working memory in both domains, and visuospatial working memory specifically in the domain of mathematics. Surprisingly, we also found significant direct and indirect relations with/via shifting. This is contrary to what we found in our model with dichotomous outcome variables, as there shifting was not a significant predictor of low academic achievement or

mediator between physical fitness and academic achievement. It thus seems that shifting is important for academic achievement, but is not specifically predictive of low academic achievement. That is: low academic achievers are not necessarily characterized by low shifting ability. This conclusion is in line with previous research in Dutch students with learning difficulties, where students with learning difficulties did not show impaired shifting performance compared to their peers without cognitive difficulties (van der Sluis, de Jong, & van der Leij, 2004). Alternatively, the non-significant relation between shifting and low academic achievement when using a dichotomous outcome variable could be attributed to the loss of statistical power when using a dichotomous instead of a continuous outcome variable.